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Critical Current Test of Liquid Hydrogen Cooled HTC Superconductors under External Magnetic Field

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Abstract

High-Tc (HTC) superconductors including MgB_2 will show excellent properties under temperature of Liquid Hydrogen (LH_2:20K), which has large latent heat and low viscosity coefficient. In order to design and fabricate the LH_2 cooled superconducting energy devices, we must clear the cooling property of LH_2 for superconductors, the cooling system and safety design of LH_2 cooled superconducting devices and electro-magnetic property evaluation of superconductors (BSCCO, REBCO and MgB_2) and their magnets cooled by LH_2. As the first step of the study, an experimental setup which can be used for investigating heat transfer characteristics of LH_2 in a pool and also in forced flow (circulation loop with a pump), and also for evaluation of electro-magnetic properties of LH_2 cooled superconductors under external magnetic field (up to 7 T). In this paper, we will show a short sketch of the experimental set-up, practical experiences in safety operation of liquid hydrogen cooling system and example test results of critical current evaluation of HTC superconductors cooled by LH_2.

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Keywords: liquid hydrogen; HTC superconductor; critical current

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1. Introduction

Hydrogen related technology is now developing as one of the important solutions for innovative energy infrastructure for reduction of CO_2 emission. Future clean energy system should be a hybrid system with combination of electric power system and hydrogen energy supply chain. Liquid hydrogen may be a candidate for an energy carrier in the hydrogen supply chain, but liquefaction energy is not so small. If liquid hydrogen is used as a coolant for High-Tc (HTC) superconducting devices, which might be key components for the hybrid energy system, the cryogenic energy can be used effectively. Hydrogen can be used for not only coolant of the superconducting power devices but also energy storage for long period in electric power system.

By now, HTC superconductors, such as REBCO and BSCCO are usually cooled by liquid nitrogen (77K), but will show excellent properties under temperature of 15-40K. Liquid Hydrogen (LH_2:20K), which has large latent heat, low viscosity coefficient, is expected as an excellent coolant.

However, there has been a lack of extensive heat transfer data of LH_2 in forced flow condition for superconductor cooling. And, due to handling difficulties of LH_2, there are only few papers on the properties of LH_2 cooled superconductors, especially under external magnetic field. In order to design and fabricate the LH_2 cooled superconducting energy devices, we must clear the followings.

1. Cooling property of LH_2 for superconductors
2. Cooling system design of LH_2 cooled superconducting devices
3. Safety design of LH_2 cooled superconducting device
4. Electro-magnetic property evaluation of superconductors (BSCCO, REBCO and MgB_2) and their magnets cooled by LH_2
5. Practical experiences in safety operation of LH_2 cooling system

As the first step of the study, an experimental setup which can be used for investigating heat transfer characteristics of LH_2 in a pool and also in forced flow[1],[2], and also for evaluation of electro-magnetic properties of LH_2 cooled superconductors under external magnetic field (up to 7 T) was designed and made[3]. We reported the test results on the critical current of PIT-MgB_2 short wire cooled by LH_2 under magnetic field up to 1.2 T [4].

In this paper, we will show a short sketch of the experimental set-up, and example test results of critical current evaluation of IMD(internal Magnesium Diffusion)-MgB2 superconductor cooled by LH_2 under magnetic field up to 5.5T .

2. Experimental Apparatus

2.1. Experimental cryostat for critical current test of LH2 cooled superconductor under magnetic field

Fig.1 shows the schema of LH_2 test cryostat. The cryostat (61L) has 309.5 mm inner diameter and has 2122 mm height. The LH_2 Cryostat is set coaxially in a bore area of liquid helium (LHe) cryostat (175L) in which an Nb-Ti superconducting magnet (112.35H, 175A) cooled by LHe is equipped. Magnetic field of the test area with LH_2 can be set to 0-7.0 T. Pressure in the LH_2 test cryostat can be set to 0.1-2.0 MPa by use of the feed hydrogen gas line. The bulk-liquid temperature can be changed by use of the sheathed heater equipped at the bottom of the cryostat. Electric current can be applied to the test sample up to 800 A by use of DC power sources. Three current lead through the top flange are covered with blanket (corrugated pipe) pressurized slightly positive by nitrogen gas in order to prevent an explosion failure.

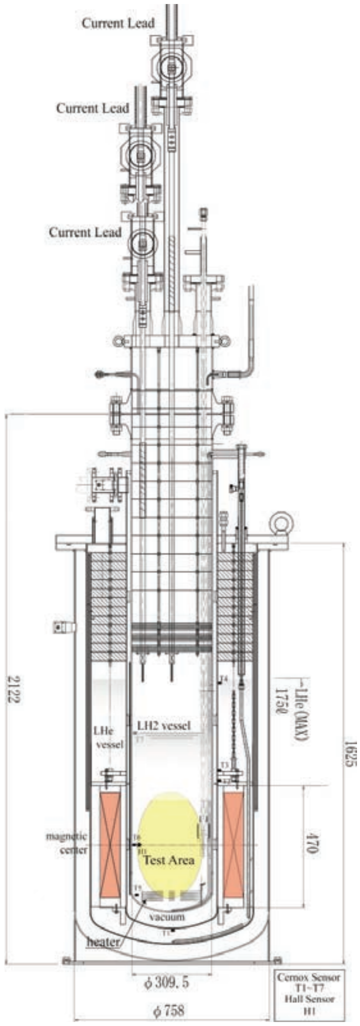

Fig.1 Experimental cryostat for critical current test of LH_2 cooled superconductor under magnetic field.

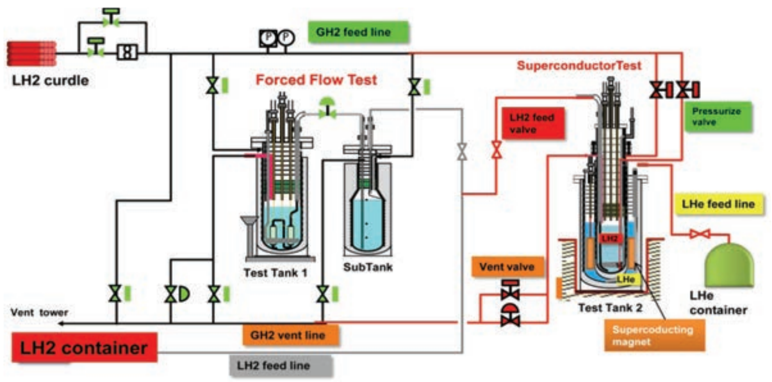

Fig.2 Experimental system

2.2. Experimental system

The schematic diagram of the experimental system is shown in Fig. 2. The system is designed to carry out experiments for cooling properties of LH_2 with pool and forced flow, and for electro-magnetic property evaluation experiment of LH_2 cooled superconductors under magnetic field. Major components of the system are a cryogenic test tank1, a cryogenic sub tank (receiver tank), and a LH_2-LHe hybrid test tank2 described before, a transfer tube with a flow control valve between the test tank1 and the sub tank, a gaseous hydrogen feeding line from compressed hydrogen clustered cylinders and vent lines.

The experimental system is installed in an explosion-proof laboratory, in which two hydrogen leak detectors are equipped on the ceiling. During the experiment, the experimental system is remotely operated with optical communication network in a control room 71 m far from the laboratory.

3. Critical Current Measurement Test

3.1. Test MgB_2 wire

The schema of the Fe sheathed IMD MgB_2 wire is shown in Fig. 3. The test MgB_2 wire was single filament wire fabricated by IMD process by Kumakura Group (NIMS). Coronene ($C_{24}H_{12}$) was added to the boron powder in a fabricating process. The amount of coronene added to boron powder was 5 at%. The test sample wire was 40 mm in length, 0.614 mm in diameter.

The distance between current leads was 30 mm, and that between voltage taps were 10 mm. The outer voltage tap was used for the burn-out detector. The copper plates were soldered at both end of the test wire, and the copper current leads were soldered on the copper plates. Additionally, the BSCCO power leads were soldered at both end of the test wire in order to avoid the joule heat generation from the power leads. The voltage taps were soldered on the sample surface. The test sample was set in the cryostat with its length direction horizontal. The plate made of FRP was set close to the test wire in order to avoid deformation caused by Lorentz force.

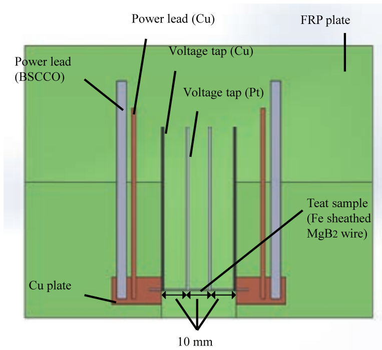

Fig.3 Test sampe of IMD MgB_2 short wire and set-up.

3.2. Experimental procedure

The test sample was set in the center of the test area of the cryostat immersed in LH_2. The bulk-liquid temperature was set to 21, 24, 27 and 29 K with the pressure of 0.1, 0.3, 0.5 and 0.8 MPa, respectively. All tests were carried out under the saturated condition. The magnetic field was set to 0 – 5.5 T by use of the Nb-Ti superconducting magnet cooled by LHe. Electrical current was controlled to increase linearly and shut off automatically to avoid burn-out. Current sweep rate was about 10 A/s.

The critical current (I_C) was obtained from the electrical field and transport current (*E-I*) property as shown in Fig. 4 (21 K, 0.1 MPa) with the external magnetic field as a parameter. The critical current was determined under the tap voltage criterion of 1μV/cm. Temperature rise at the voltage appearance is estimated to be slightly small because the nucleate boiling starts immediately under the saturated condition.

Fig. 5 shows critical density versus magnetic field (J_c-B) characteristics with various temperatures (solid symbols). The critical current density J_c was obtained from Ic divided by cross sectional area of MgB_2. The n-values with each temperature as a function of external magnetic field are shown in Fig.6. The degree of accuracy is insufficient in high magnetic field since the sample wire is rather short. The test area of the experimental set-up has enough large for the longer wire test in the next step.

Open symbols show the results of another IMD-MgB_2 wire measured with conduction cooling reported by Li, et.al [5]. The properties with low-B and large-J_c were able to be evaluated due to the small temperature rise with stable cooling condition immersed in LH_2.

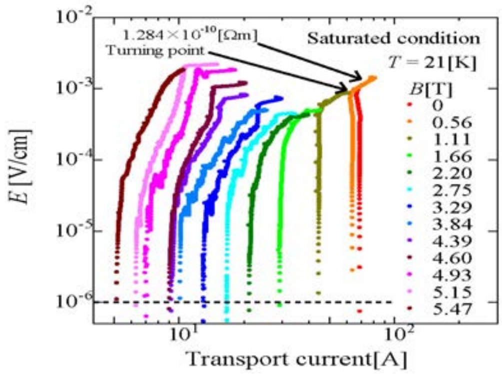

Fig.4 Electrical field and transport current (E-I) property (21 K, 0.1 MPa) with magnetic fields as a parameter.

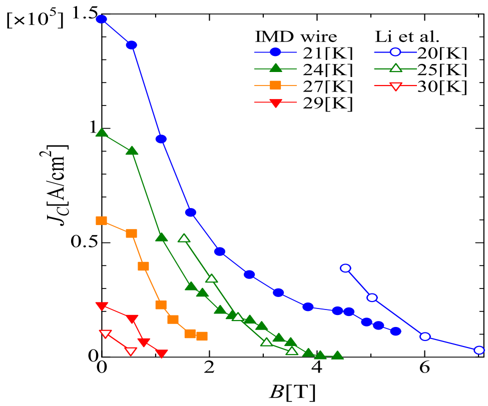

Fig.5 (J_c-B) characteristics(solid symbols). Open symbols show the data (another wire) measured with conduction cooling ([5]).

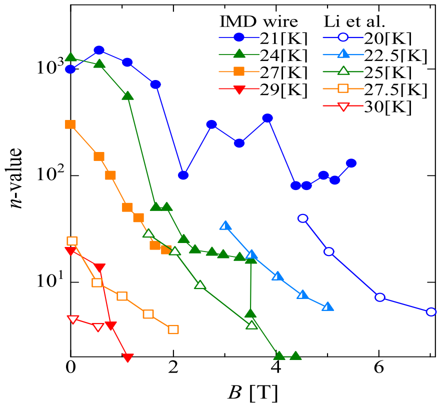

Fig.6 (n-value-B) characteristics (solid symbols). Open symbols measured with conduction cooling ([5]).

4. Conclusion

We designed and made an experimental setup which can energize superconducting wires immersed in LH_2 with the current of up to 500 A under the condition of external magnetic field up to 7 T and pressure up to 1.5 MPa. Using this experimental set-up, critical current tests were carried out using IMD-MgB_2 superconducting short wire under various external magnetic field conditions.

Acknowledgements

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